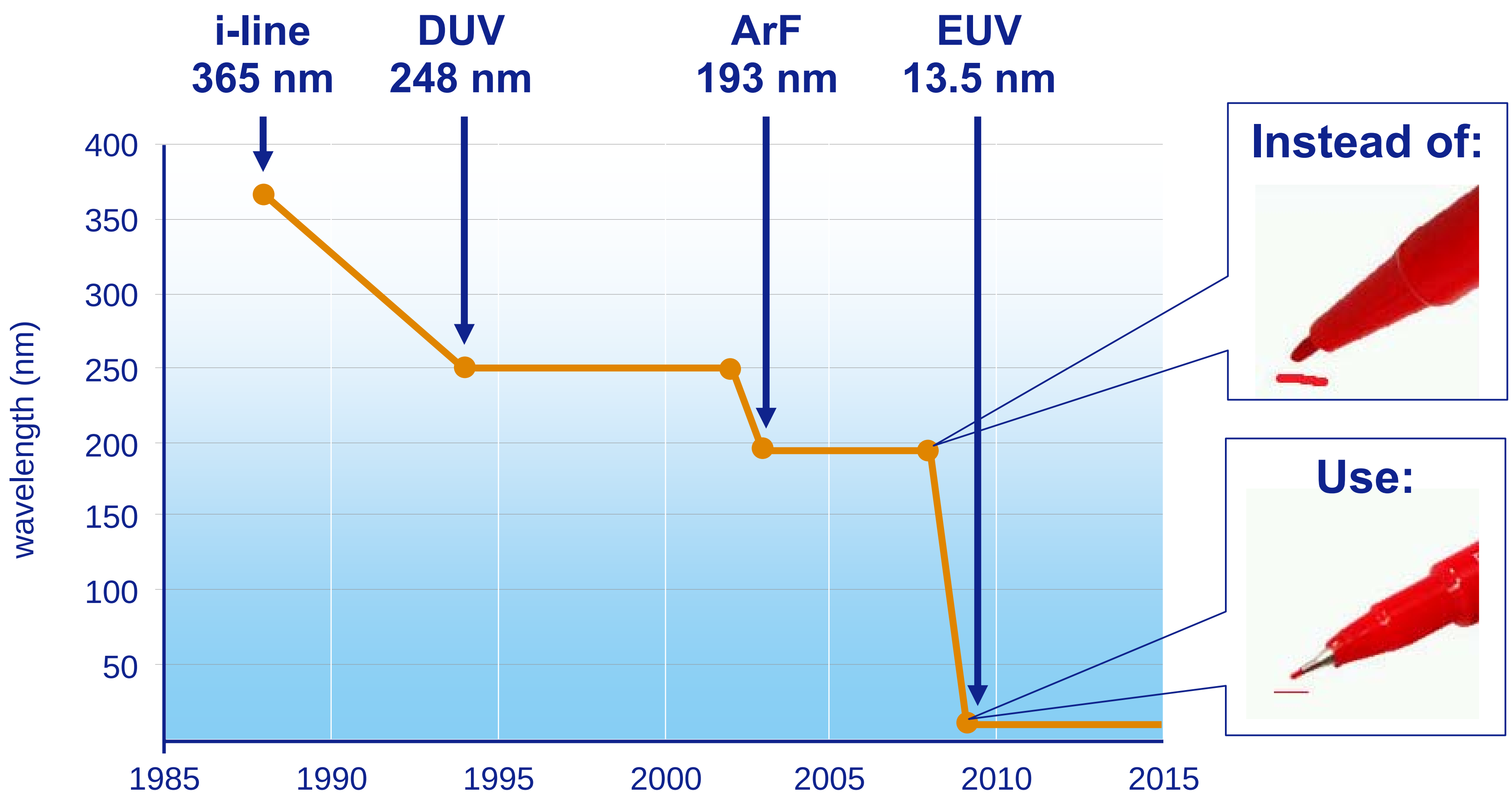
EUV: past, present and prospects

Jos Benschop

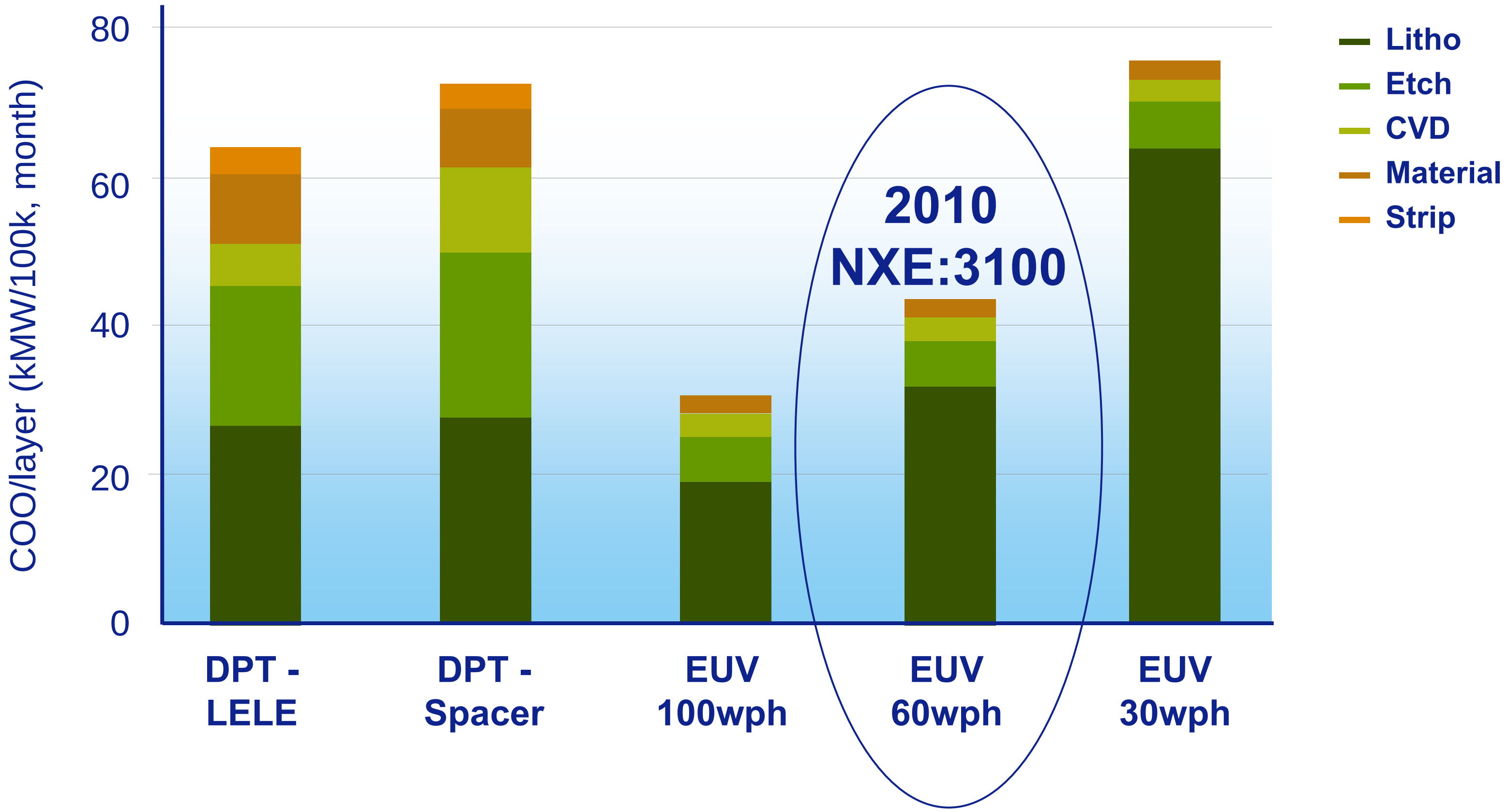
Agenda

- Why EUV
- History
- Key system technology
- ASML system roadmap
- Infrastructure
- Summary & conclusions

Extreme Ultra Violet light enables shrink



Customers acknowledge: EUV is cost effective



Source: hynix SPIE 2009

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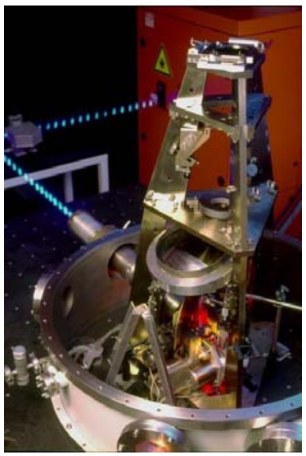
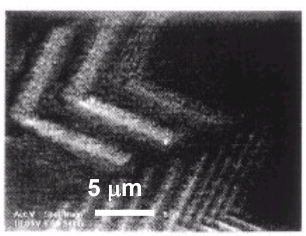
EUV small field imaging

'90	'91	'92	'93	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07	'08	'09

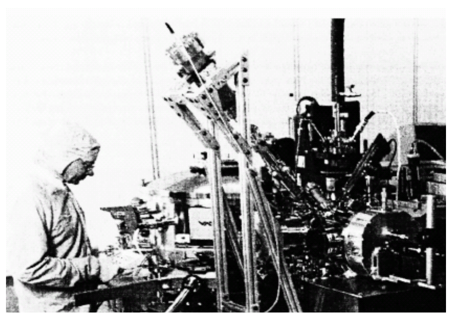
FOM
NA: 0.15

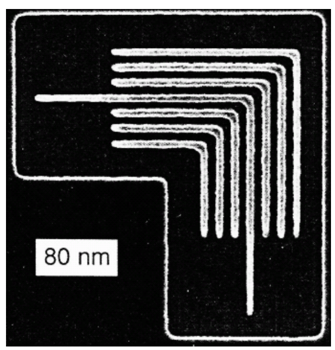




F. Bijkerk, et al., “Design of an extended image field soft x-ray projection system, Monterey, CA, USA, 1991 (OSA).

’91=>’95 (upgrade) 10x
NA: 0.08 => 0.1

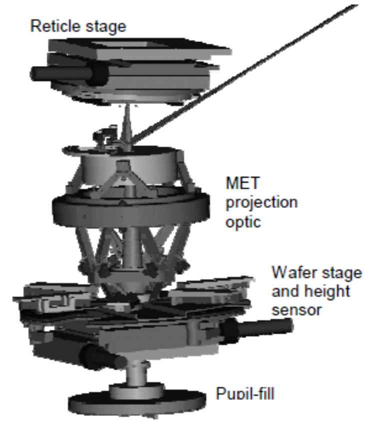


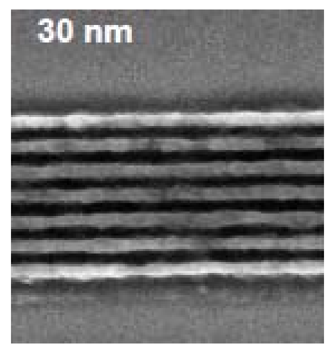


D. A. Tichenor,” Development of a Laboratory Extreme

Ultraviolet Lithography Tool”
SPIE Vol. 2194 (1995)

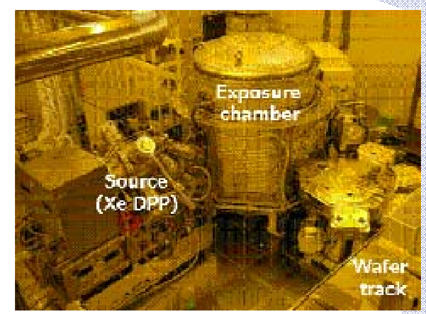
MET
NA: 0.3

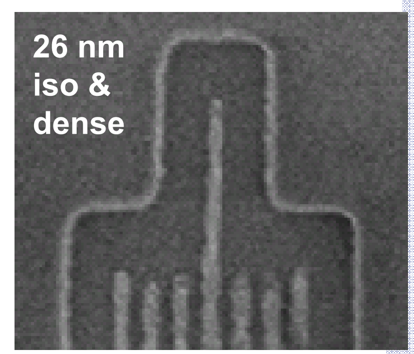




Patrick Naulleau,” EUV microexposures … 0.3-NA MET”
SPIE Vol. 5751 (2005)

SFET
NA: 0.3



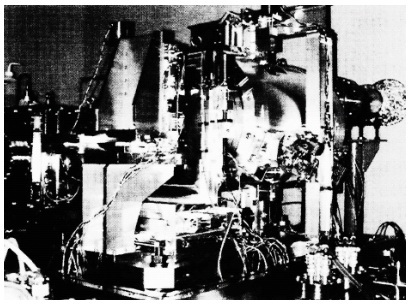


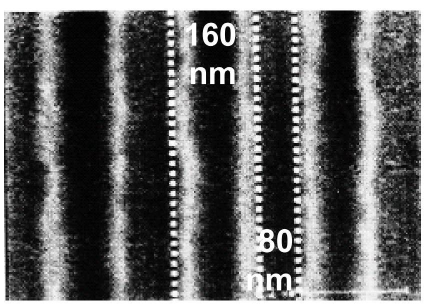
Yuusuke Tanaka, “Fidelity of rectangular patterns printed with 0.3-NA MET optics” SPIE Vol. 6517 (2007)

EUV full field imaging

'00	'01	'02	'03	'04	'05	'06	'07	'08	'09

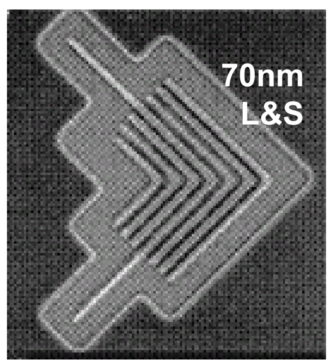
Himeji
NA = 0.10





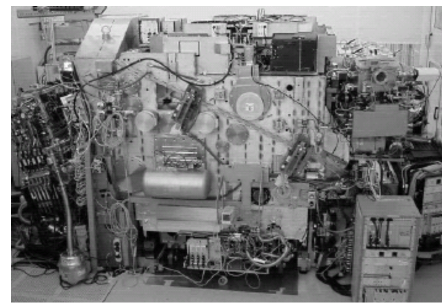
H. Kinoshita, “Recent advances of 3-aspherical mirror system for EUVL”, SPIE Vol. 3997 (2000)

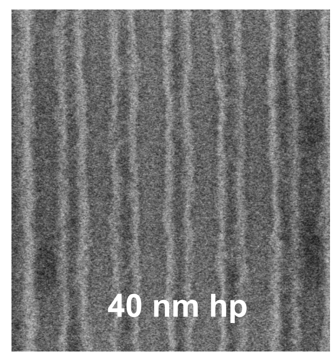
ETS
NA = 0.10



Daniel A. Tichenor, “Initial Results from the EUV Engineering Test Stand, SPIE Vol. 4506 (2001)

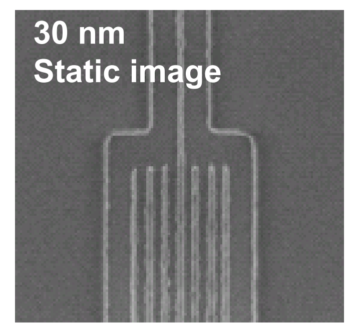
Alpha-Demo
NA = 0.25





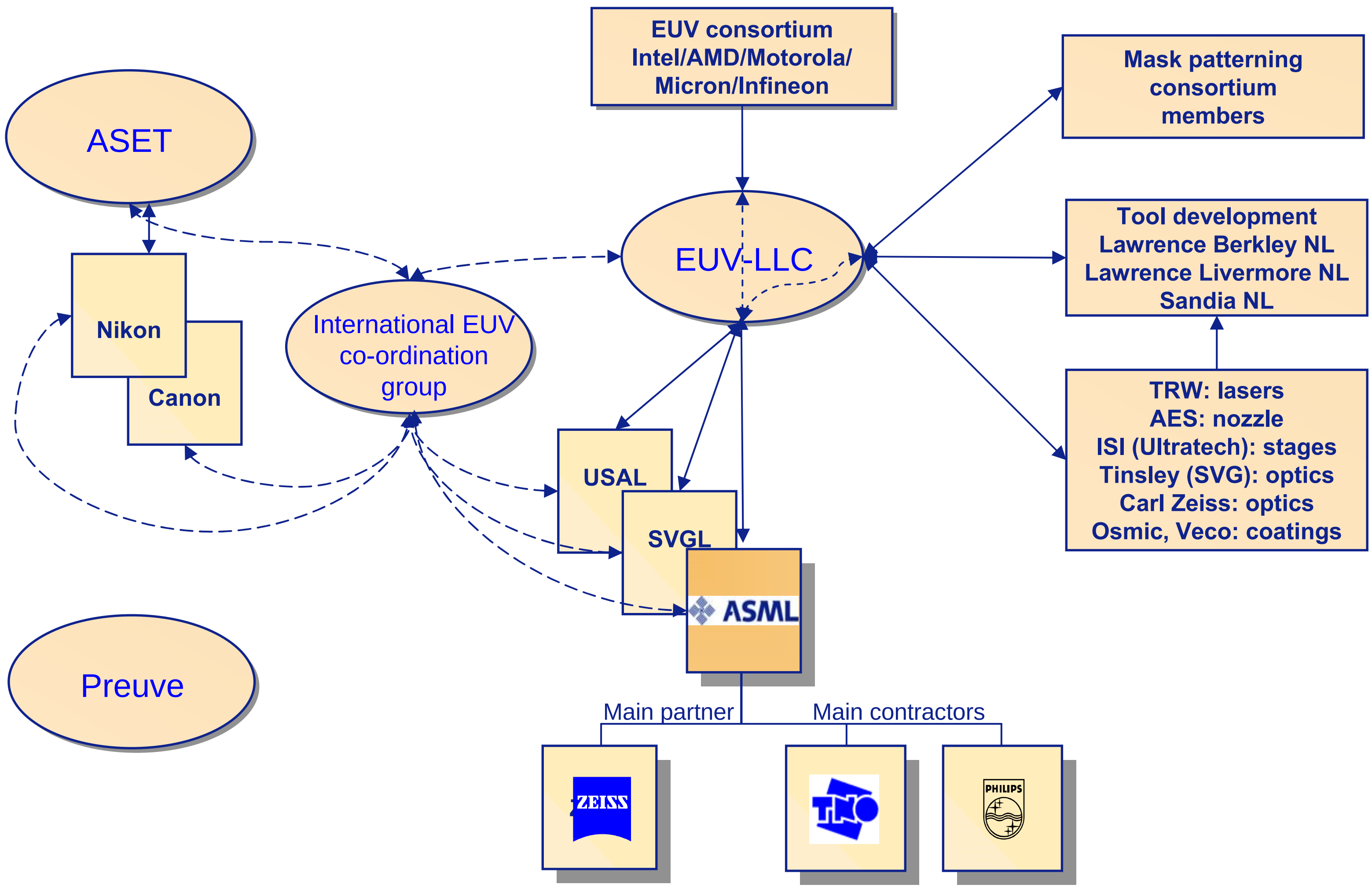
Hans Meiling, “First performance results of the ASML alpha demo tool”, SPIE Vol. 6151 (2006)

SELETE EUV1
NA = 0.25



Ichiro Mori, “Selete’s EUV program: progress and challenges” Vol. 6921, (2008)

Worldwide consortia: 2001 snapshot

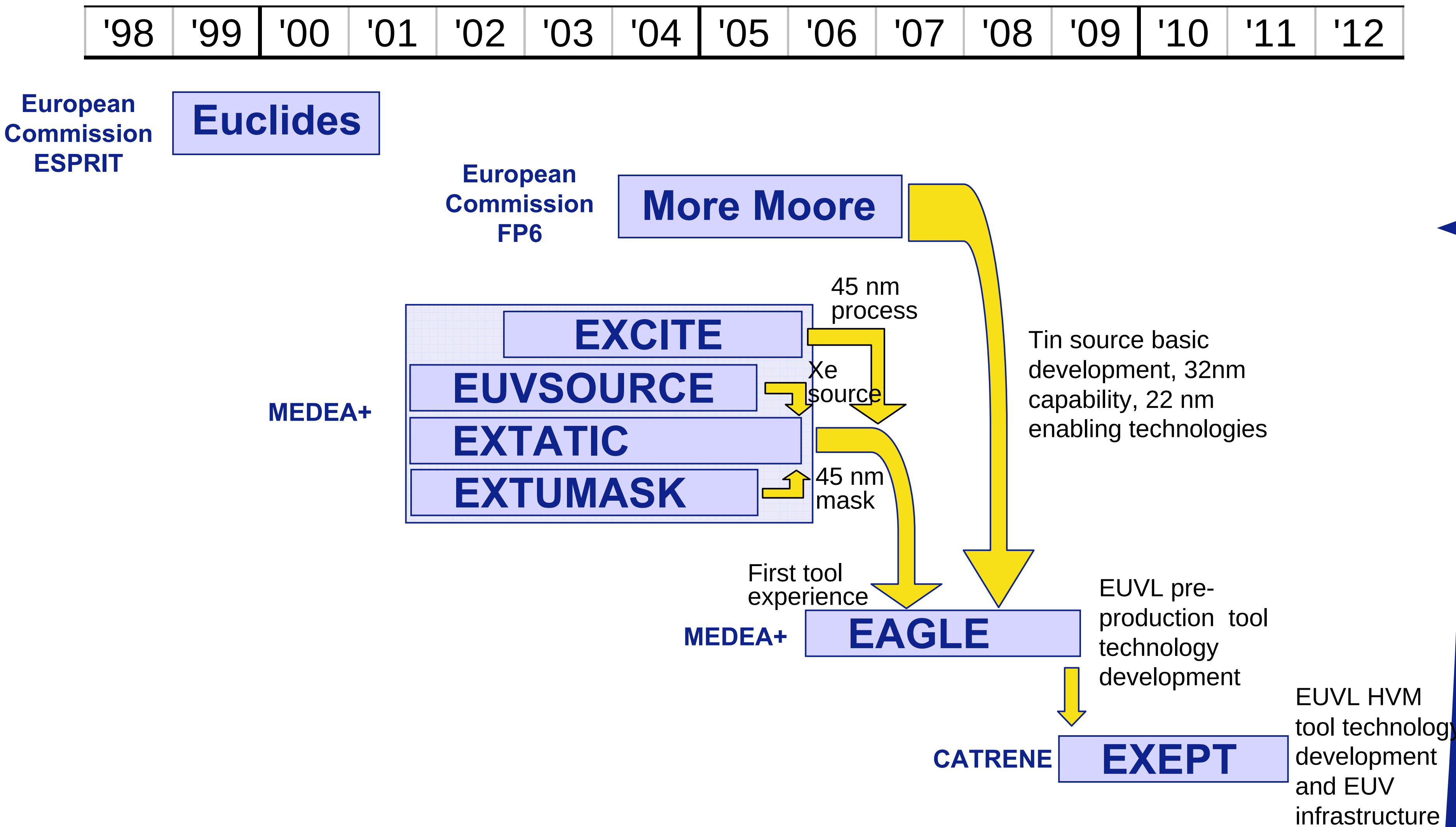


ASML

Worldwide EUV partners ASML 2009

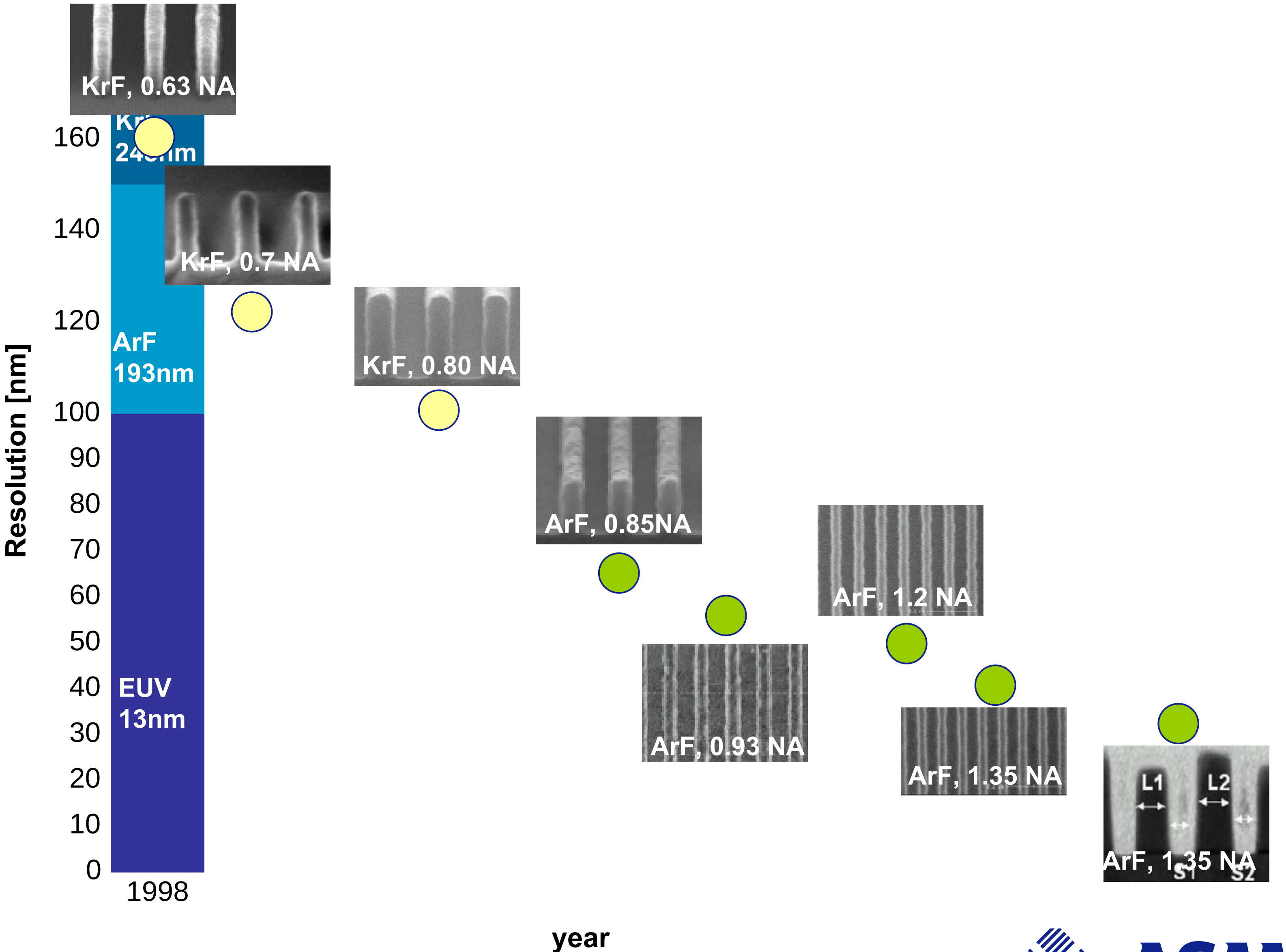
- Advanced Mask Technology Center
- Imagine Optic
- Xenocs
- Infineon technologies
- SIGMA-C
- Sagem Défense Sécurité, Groupe SAFRAN
- ioe
- AZ Electronic Materials
- Universität Bielefeld, Fakultät für Physik
- ENEA C.R. Frascati
- IOM
- SCHOTT lithotec
- ELDIM
- AIS
- cea leti
- ROTH & RAU
- Fraunhofer Institut Integrierte Systeme und Bauelementetechnologie
- Johannes Gutenberg Universität Mainz
- TU Delft
- elettra
- PTB
- eppra, European Pulsed Power Research Applications
- FOCUS GmbH, Instruments for Electron Spectroscopy and Surface Analytics
- ALCATEL THALES
- freescale semiconductor, Launched by Motorola
- ST
- XTREME technologies
- CNRS, Centre National de la Recherche Scientifique
- PHILIPS
- FOM
- imel
- HAMATECH APE, A member of the Singulus Group
- Media Lario Technologies
- TASC
- JENOPTIK JENA, Laser.Optik.Systeme.
- Paul Scherrer Institut PSI
- TNO
- PhysTeX
- Information Society Technologies
- AIXUV EUV-Technology
- imec
- Institute of Spectroscopy, Russian Academy of Sciences, 1968
- CATRENE
- ZEISS, CARL ZEISS SMT
- ASML

Ongoing European funding support



ASML

Wavelength transition: a moving target



Agenda

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  - Source
  - Optics
- ASML system roadmap
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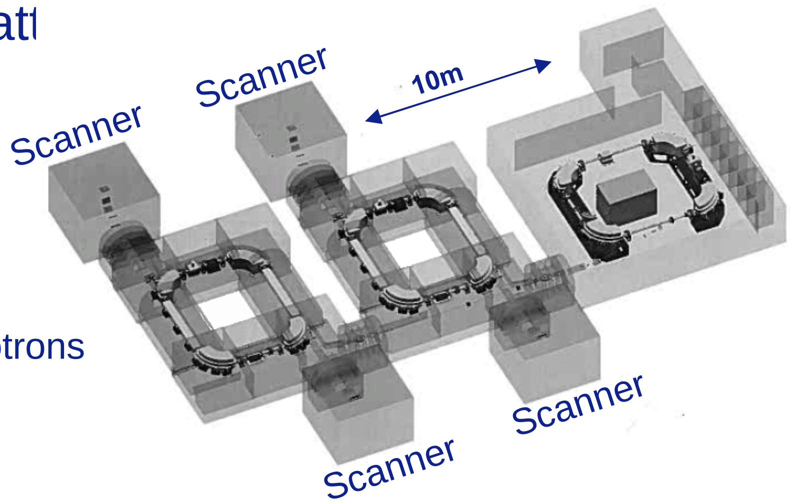
Several EUV source types are being used

- Beam line (synchrotron, wiggler, undulator)
- Discharge Produced Plasma (DPP) source
- Laser Produced Plasma (LPP) source

Beam line (synchrotron, wiggler, undulator)

- Used for EUV projection lithography,
  e.g. Kinoshita et al. using Himiji beamline, Attwood et al. using Berkely beamline
- Used for EUV interference systems
  e.g. Paul Scherrer Institute studies on EUV resist
- Studied for mass production by Oxford Instruments in EUCLIDES project. Max power (depending on configuration and beam current) 10~30 Watt



booster.

Two Synchrotrons

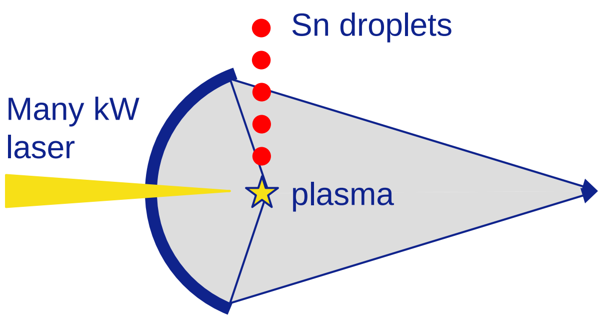
Benschop, Dinger, Ockwell, “EUCLIDES: First Phase Completed!”, SPIE Vol. 3997 (2000)

Conclusion: beam lines are not a viable technology for > 100 Watt power required for high volume mass production

ASML

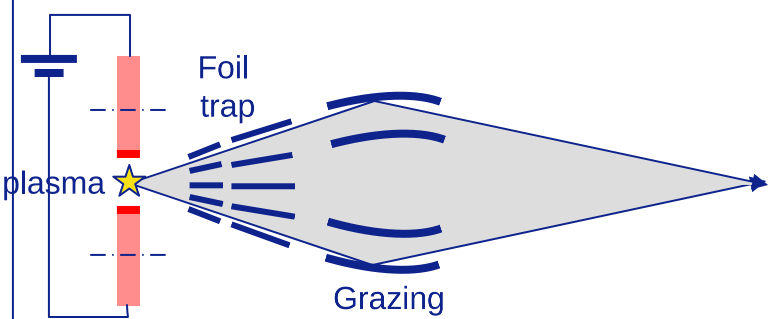
LPP vs DPP

Laser-Produced Plasma source



CO2 laser
Sn droplet target
Debris mitigation using background gas
and/or magnetic fields
Near normal multilayer collector
Pursued by: Gigaphoton, Cymer, …

Discharge Produced Plasma source

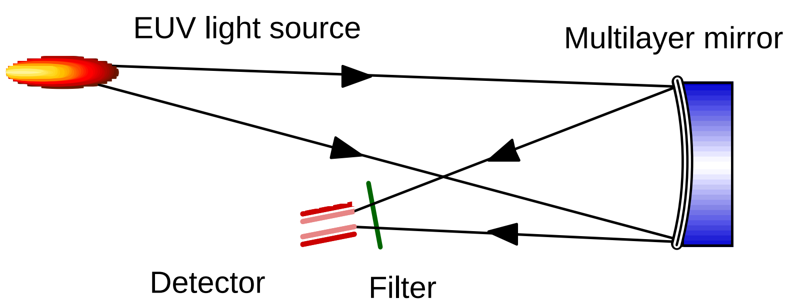


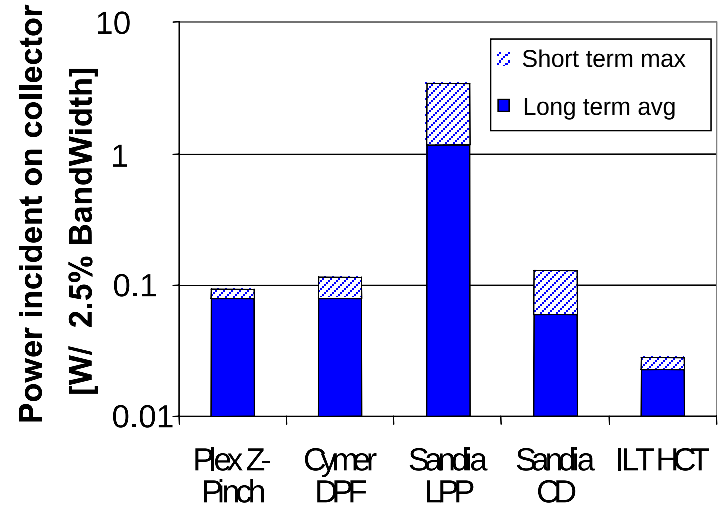
Direct conversion electricity => plasma
Xe gas or Sn solid
Debris mitigation by set of foils

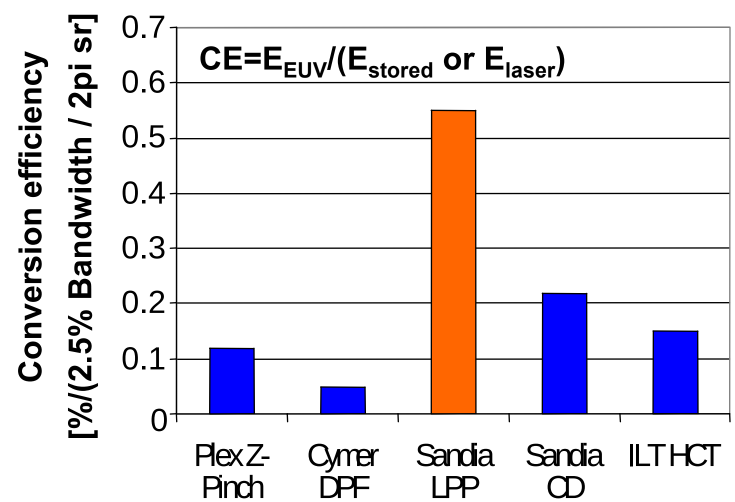
Grazing incident collector
Pursued by Philips, Extreme, …

ASML

2000: “Flying Circus” worldwide source benchmarking

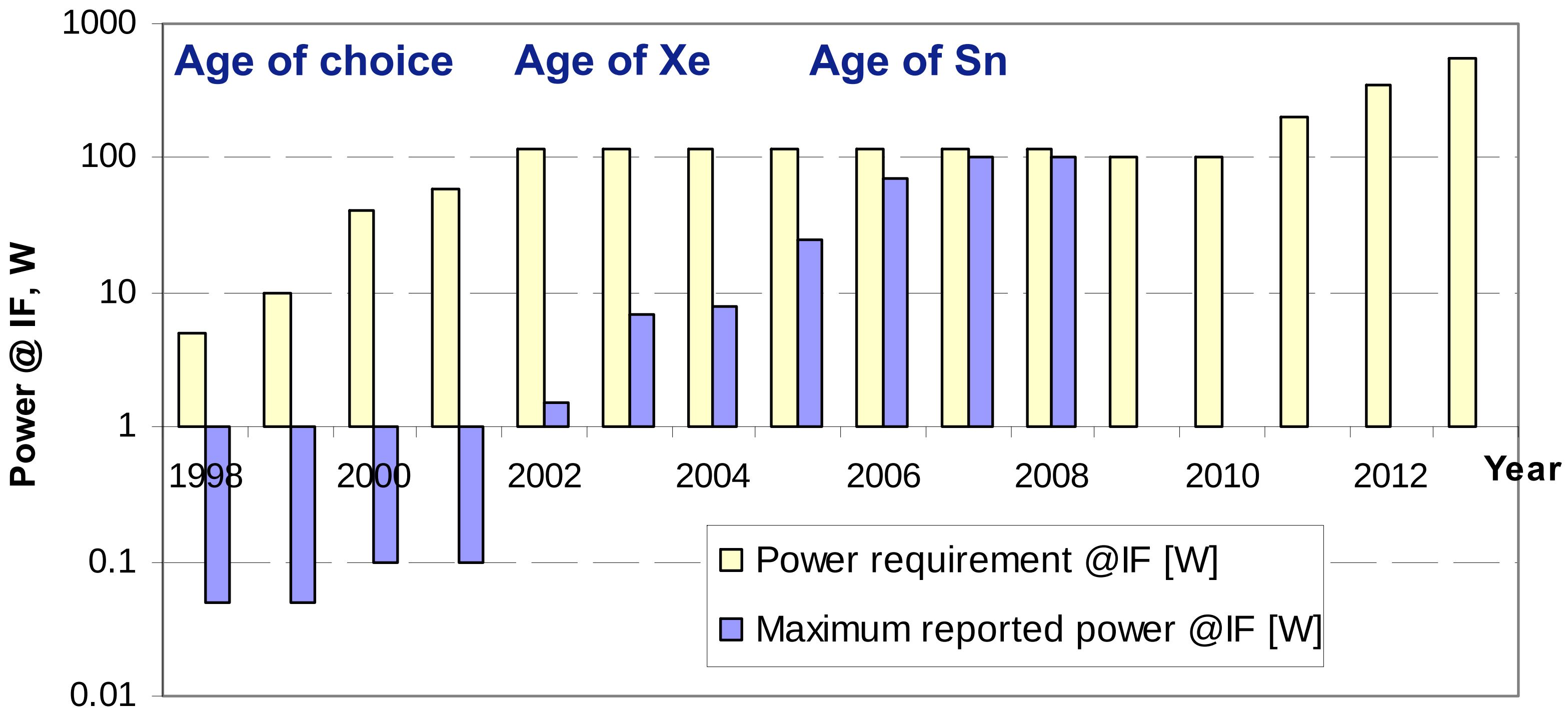






R. Stuik, H. Fledderus, P. Hegeman, J. Jonkers, M. Visser, V. Banine, F. Bijkerk, 2nd SEMATECH EUVL Symp (2000)

Gap required-achieved power has been bridged.

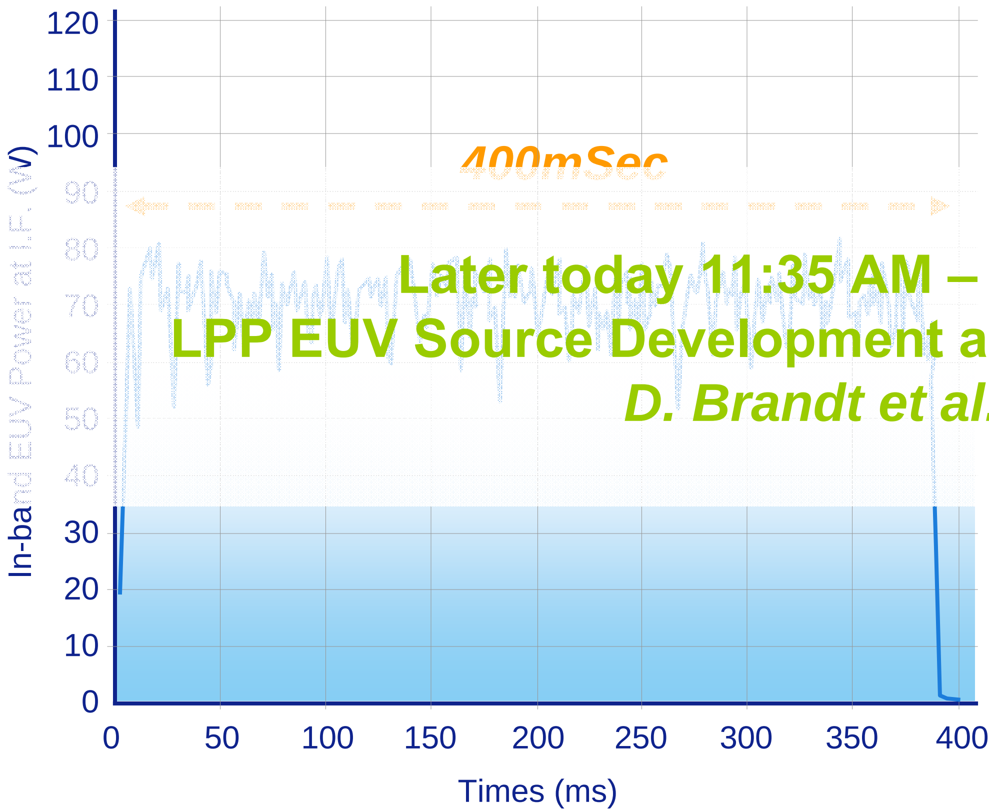


Future challenges

- **Meet power for long burst (>400msec) and high duty cycle (>80%)**
- **Higher power to cope with less sensitive resist and enable a cost effective high throughput system**

ASML

Excellent EUV Source Progress



Later today 11:35 AM – 12:00 AM

LPP EUV Source Development and Productization.

D. Brandt et al.

2H-08

- Demonstration of source feasibility
- Burst length = 1mSec
- Power = 20W

Sept-09

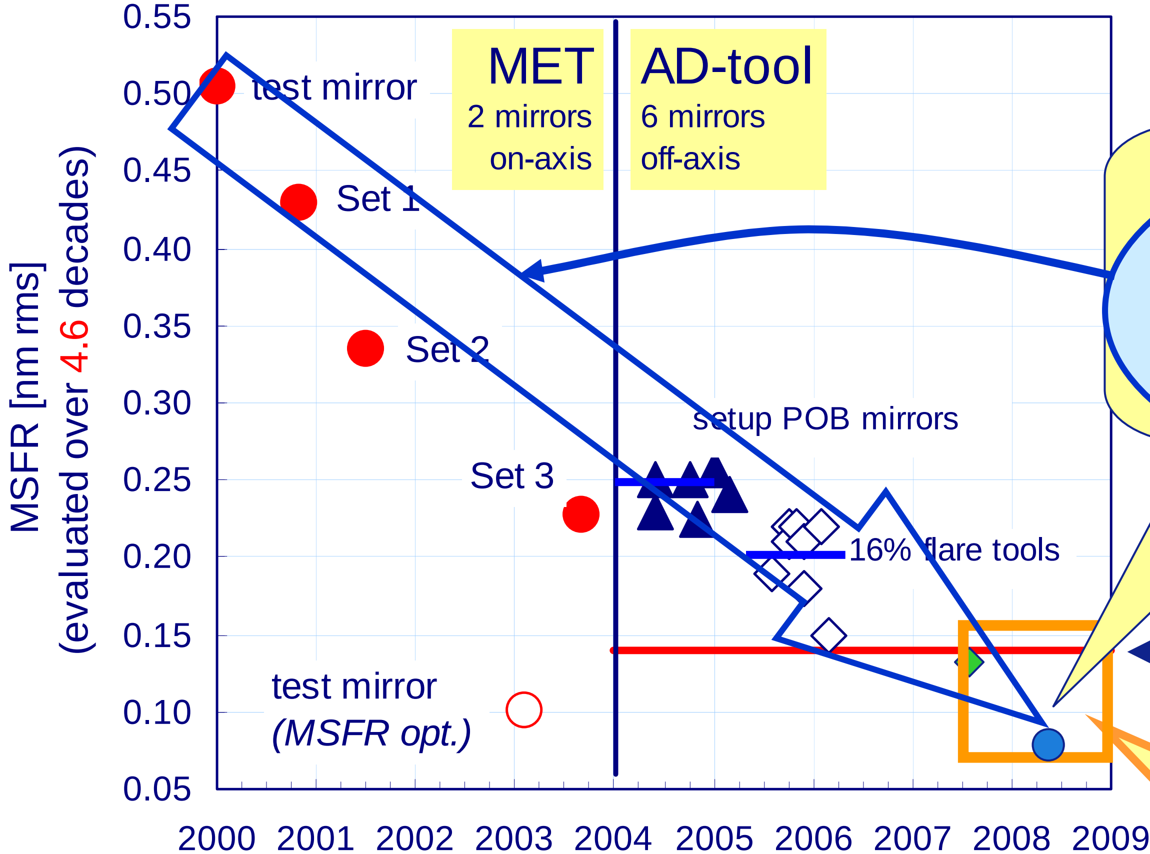
- Full size collector implemented
- Dose control implemented
- Debris mitigation operational
- Burst Length = 400mSec (full exp. field)
- Power = 70W (>3x improvement)

~ *2x power increase required for 60 WPH*

More than 30 HVM mirrors have been fabricated: Considerable reduction of the flare has been achieved

Flare is calculated for a 2 µm line in a bright field

$$Flare \propto n_{mirrors} \cdot (\mathrm{MSFR}/\lambda)^2$$



POB = Projection Optics Box

Development focuses on material, polishing, and figuring

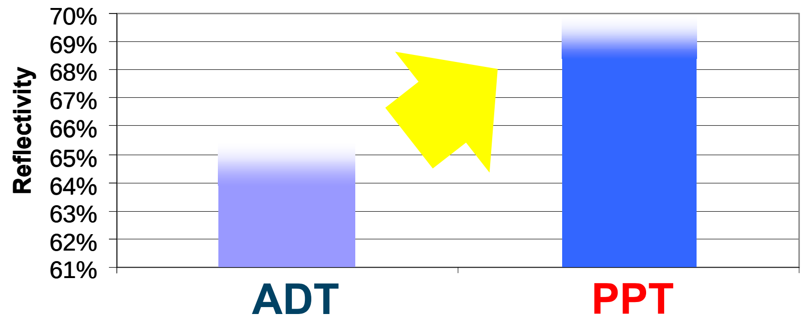
8% flare

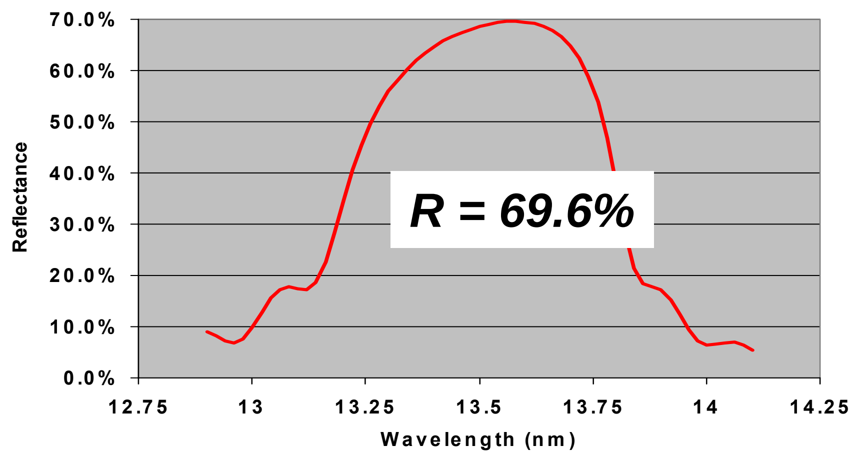
> 30 mirrors have been fabricated (all within this process window)

Close collaboration between academia and industry led to world-record multilayer coating technology

technology transfer

50% throughput gain by enhanced reflectivity





- HVM Mirror coated at FOM, measured at PTB
- Local angle of incidence (s-pol)

ASML

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- History
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  - system roadmap
    - Alpha Demo Tool
    - NXE platform
  - ongoing shrink
- Infrastructure
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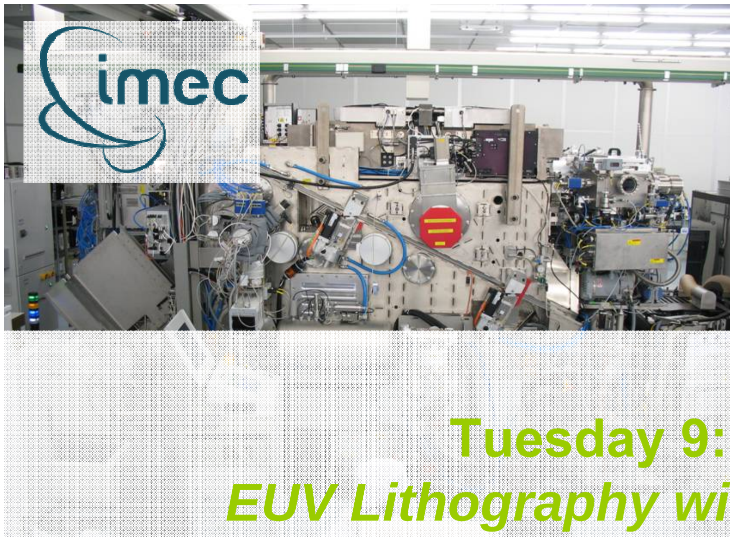
Two full field scanning Alpha Demo tools installed

Tried and tested, proved and improved since 2006



Tuesday 9:30 AM – 9:50 AM

EUV Lithography with the Alpha Demo Tools.

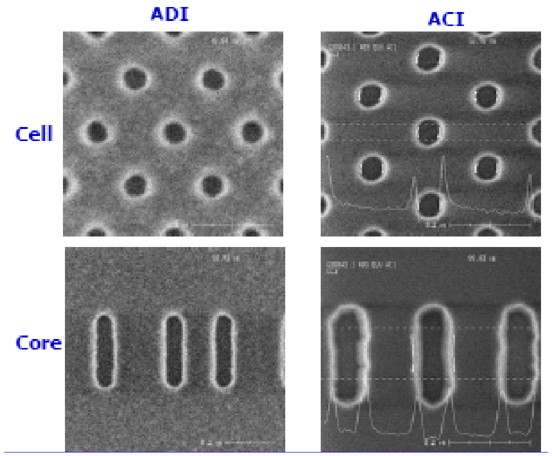
S. Lok et al.

• λ	13.5 nm
• NA	0.25
• Field size	26 x 33 mm^2
• Magnification	4x reduction
• Sigma	0.5

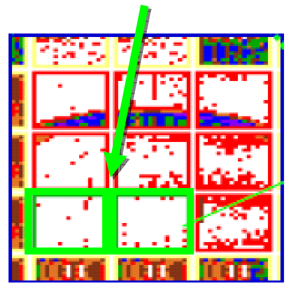
- Single stage, 300mm wafers, linked to track
- Single reticle load
- Uses TWINSCAN technology (*e.g.* focus)
- Reflective optics
- Sn discharge source

Multiple customer imaging results with EUV

First working DRAM, EUV pattern fidelity higher than for ArFi



These are working 4x DRAM's!!!

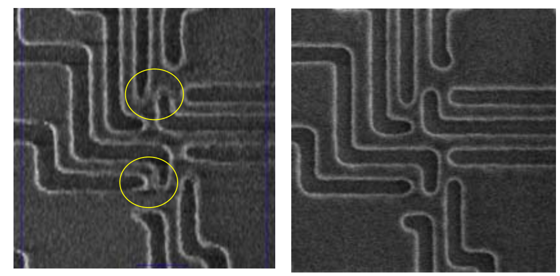


SAMSUNG

EUV Lithography: SRAM - M1 Level

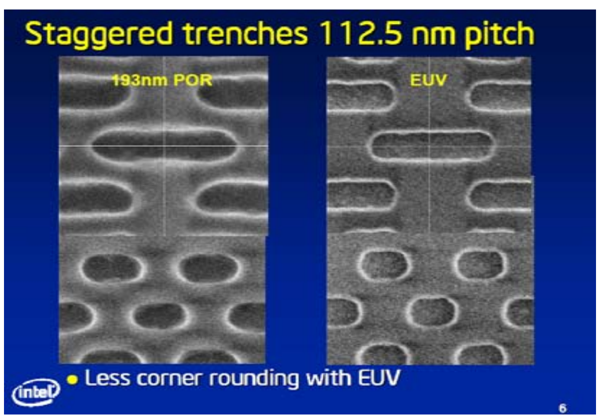
AMD

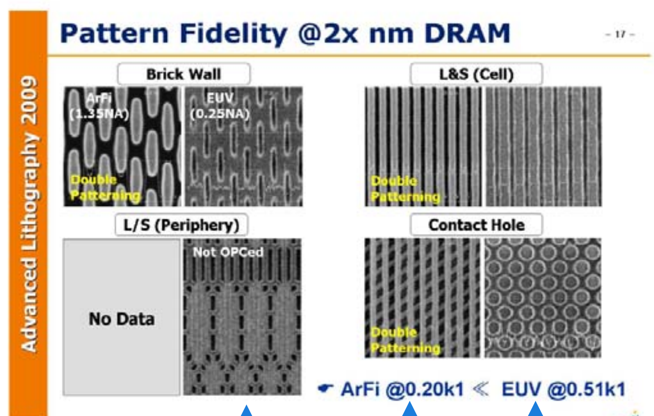
0.08 µm² SRAM Flycell



Best image by 193i Litho (Double Dipole exposures)

By EUV ADT





hynix

ArF*i* DPT

EUV ADT

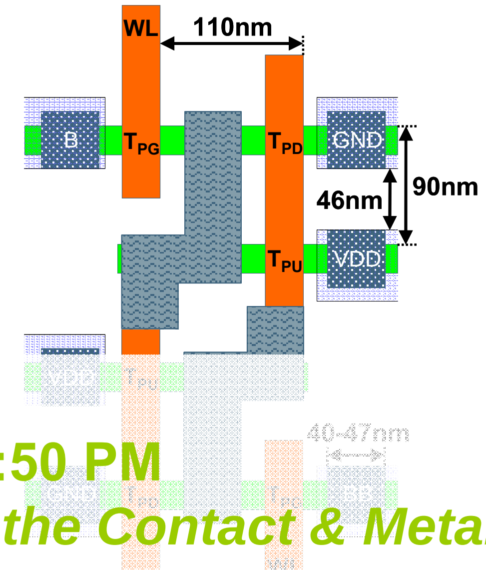
ArF*i* DPT

EUV ADT

Source: various SPIE presentations (Feb.'09)

ASML

Fully functional 22nm SRAM cell fabricated using EUVL



Wednesday 4:30 PM - 4:50 PM

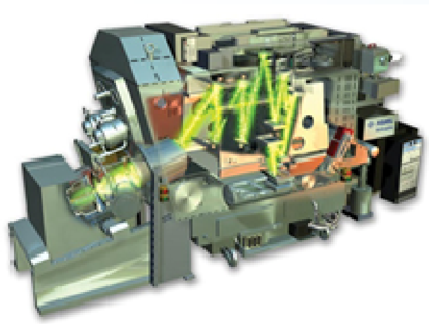
EUV Lithography Implementation on the Contact & Metal Interconnect Level of a 22nm Node 0.099 µm2 6T-SRAM Cell

A.-M. Goethals et al.

Electrically functional 0.099µm² 22nm node 6-T CMOS SRAM cells now demonstrated using EUVL for contact and M1 level patterning

Source: IMEC April '09

EUV Product Roadmap



2006

ADT

Resolution = 32 nm
NA = 0.25, σ = 0.5
Overlay < 7 nm
Throughput 5 WPH
@ 5mJ/cm²
~8W

2010

NXE:3100

Resolution = 27 nm
NA = 0.25, σ = 0.8
Overlay < 4.5 nm
Throughput 60 WPH
@ 10mJ/cm2
>100W

2012

NXE:3300B

Resolution = 22 nm
NA = 0.32, σ = 0.2-0.9
Overlay < 3.5 nm
Throughput 125 WPH
@ 15mJ/cm2
>350W

2013

NXE:3350C

Resolution = 16* nm
NA = 0.32, OAI
Overlay < 3 nm
Throughput 150 WPH
@ 15mJ/cm2
>550W

Main improvements
1) New EUV platform :NXE
2) Improved low flare optics
3) New high σ illuminator
4) New high power LPP source
5) Dual stages

Main improvements
1) New high NA 6 mirror lens
2) New high efficiency illuminator
3) Off-Axis illumination option
4) Source power increase
5) Reduced footprint

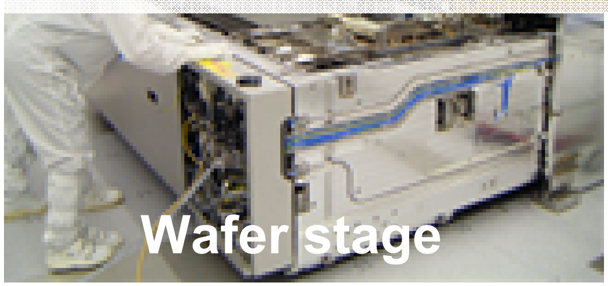
Platform enhancements
1) Source power increase

**** Requires <7nm resist diffusion length***

NXE:3100 modules being integrated in new EUV FAB
Project is on target for shipment mid 2010

Tuesday 8:30 AM – 8:50 AM
EUVL Into Production – Update on ASML's NXE Platform.
C. Wagner, J. Stoeldraijer, D. Ockwell

Wednesday, October 21, 2009
2:20 PM – 2:40 PM Optics for EUV Lithography
P. Kuerz et al.



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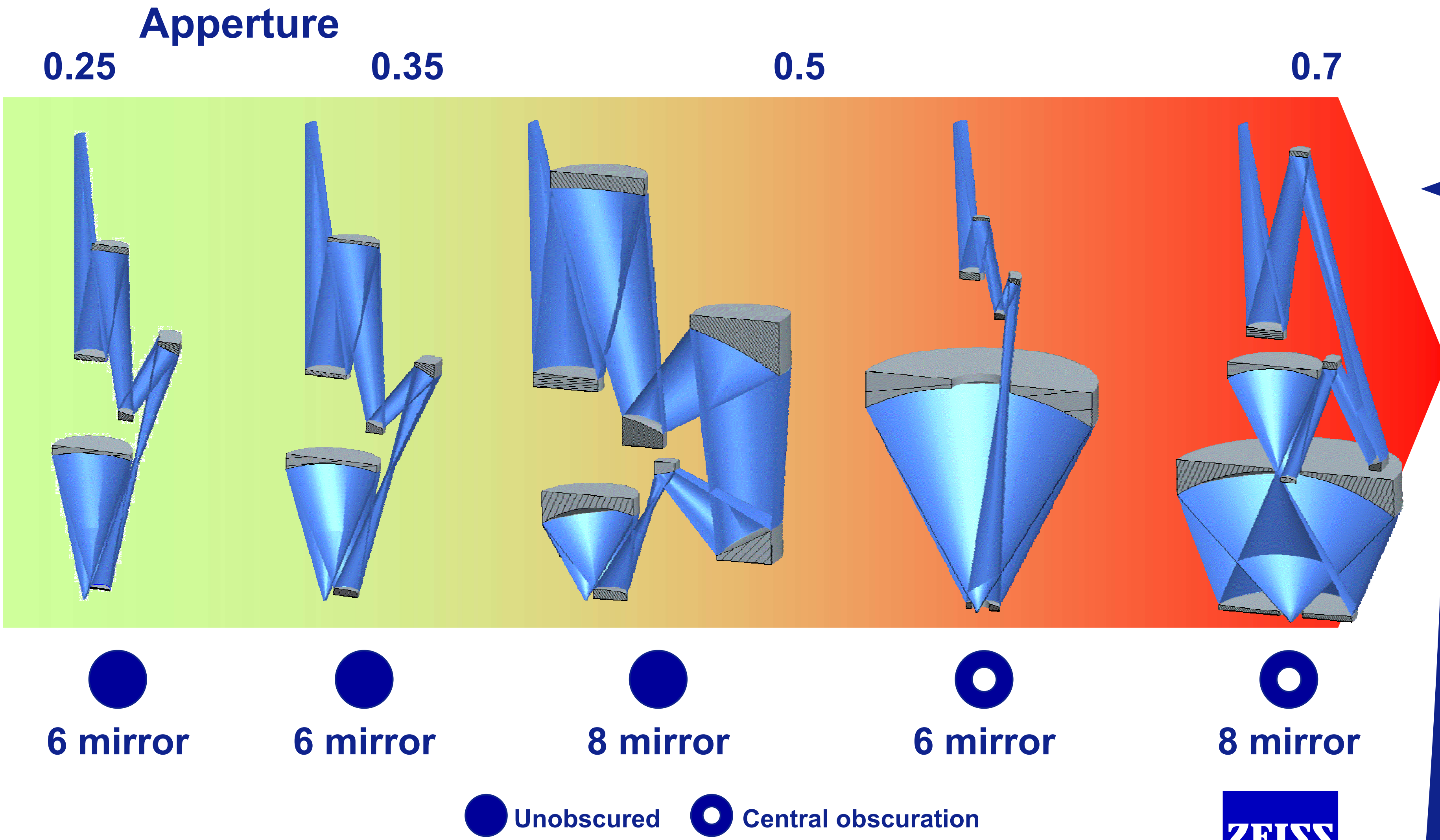
EUV extendibility possible beyond 10 nm resolution

trough increase the apertures up to 0.7



ZEISS

Reference: W.Kaiser et al, SPIE 2008 6924-4

6.x nm wavelength would enable further shrink

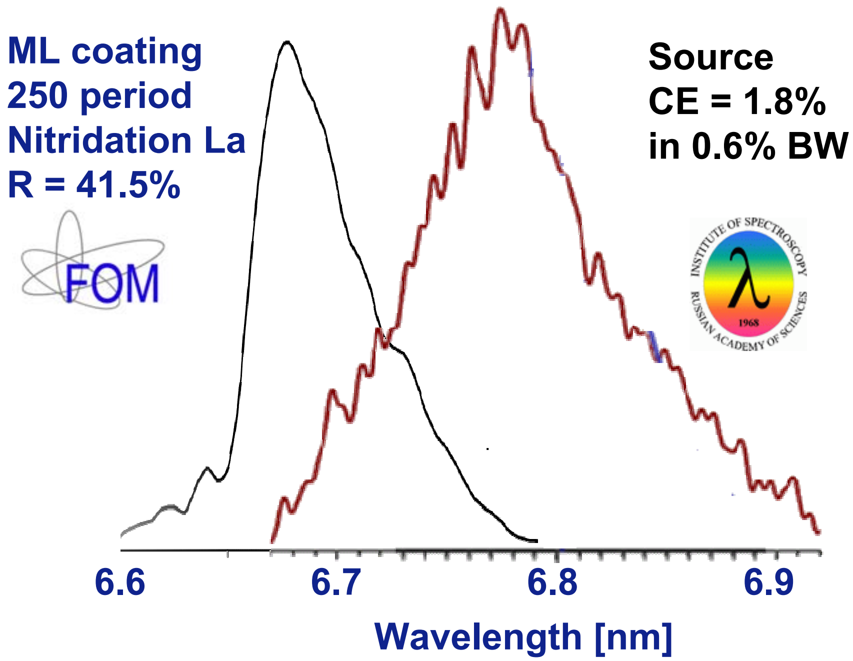
Shorter wavelengths have been investigated for lithography and other applications (e.g. water window microscopy).

Criteria are

- coating bandwidth and reflectivity
- In-band source power,
- resist sensitivity

Measured source and coating performance

Tim Tsarfati, et al. Proc. SPIE 7271, (2009)



Banine, Koshelev

Private communication

Tight requirement on optics manufacturing

- Low spatial frequency => aberrations ~ λ^{-1}
- Mid spatial frequency => flare ~ λ^{-2}
- High spatial frequency => reflectivity-loss ~ λ^{-4}

Agenda

- History
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  - Mask
  - Resist
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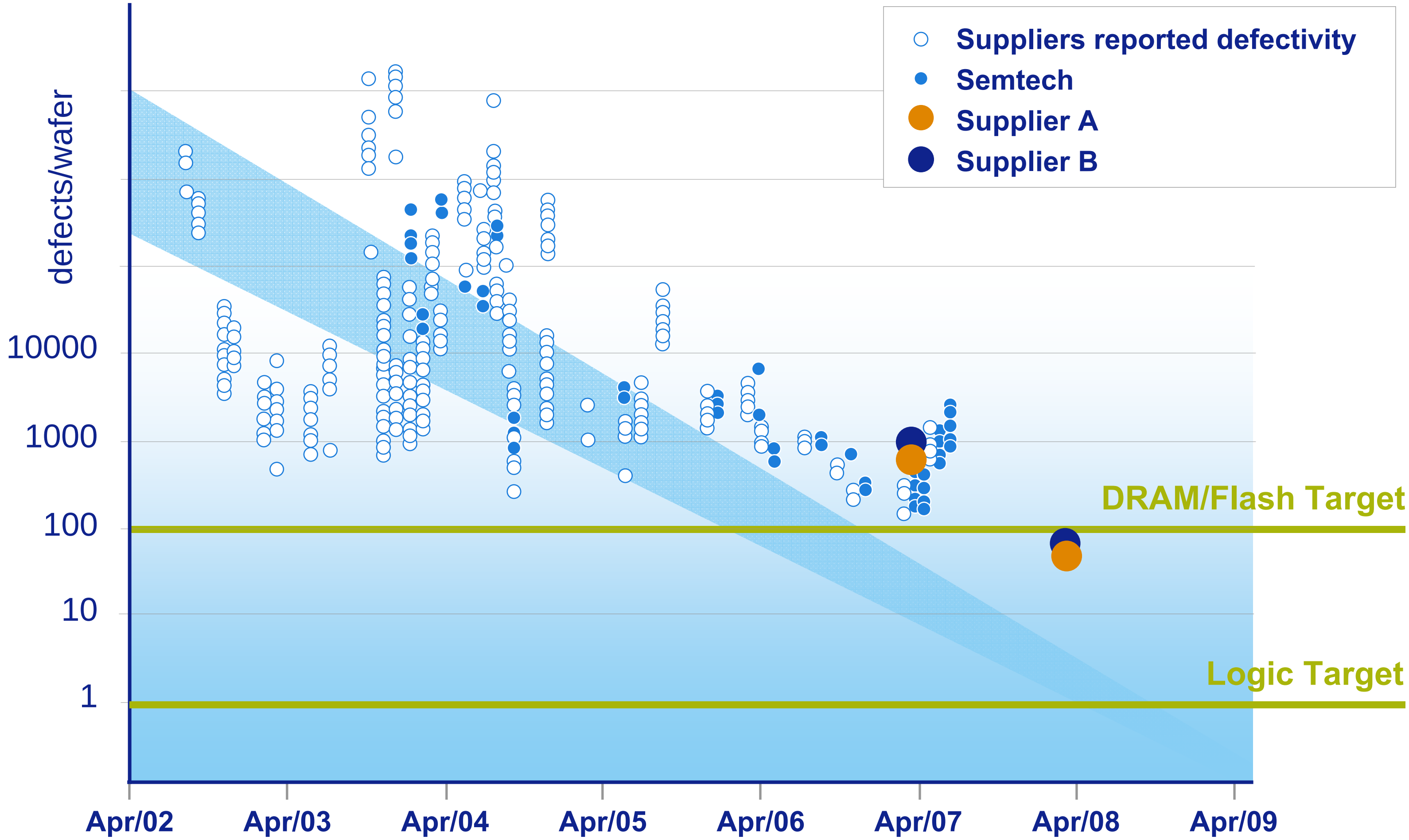
Mask developments on target

Mask defects for memory meet R&D requirements



Data Source: Sematech, Sapporo 2007

EUV Mask Inspection Tools are critical element
Commercial solutions being worked via SEMATECH WG

	Defect Size [nm] Substrate	Defect Size [nm] Blank	Substrate & Blank: Optical Tools	Substrate & Blank: Actinic Tools	AIMS & Patterned	AIMS & Patterned
Development	51, 41, 35	67, 53, 40	Lasertec M1350 (1st Generation) Lasertec M7360 (2nd Generation) M1350 & M7360 @ SEMATECH	SEMATECH Berkeley AIT Selete MIRAI	SEMATECH Berkeley AIT • 60 nm mask CD resolution • Key for defect printability understanding	Optical PMI
Pilot	20, 15	25, 20	2.5 Generation Substrate Inspection Tool (2.5G)	3rd Generation Blank Inspection Bridge Capability (3G)	AIMS Bridge Capability	Optical PMI
HVM		15		Commercial 3G Inspection Tool	Commercial AIMS Tool	<22nm Patterned Inspection

ABC = Existing Tools; [orange] = SEMATECH Pilot Line Tools; [yellow] = Production Tools

Semi compliant EUV reticle pods keep reticle clean

No 50nm particles added

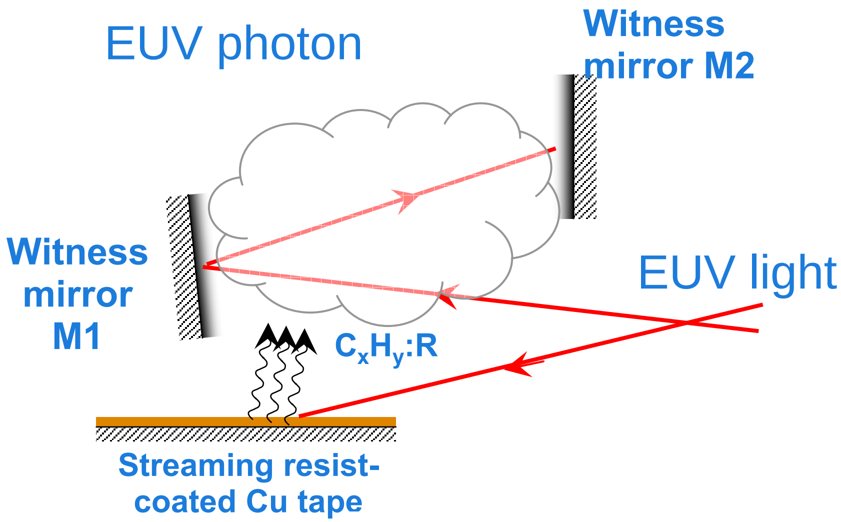
	Cycles	Adders per cycle
Complete Cycle	370	0.00
Pump and Vent	60	0.0
EIP Open/Close	1100	0.000

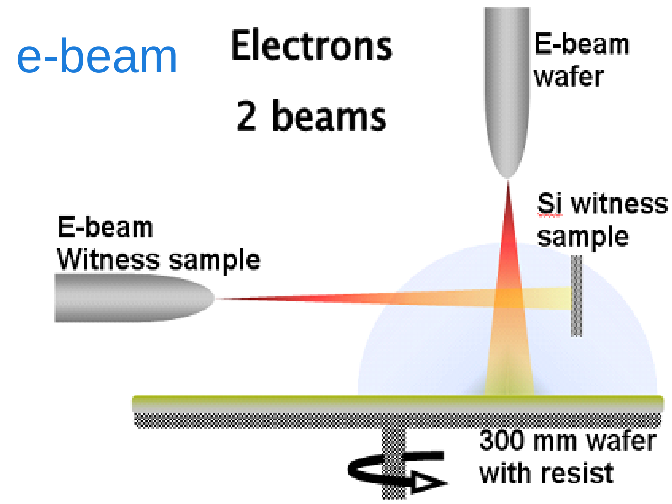
No outgassing

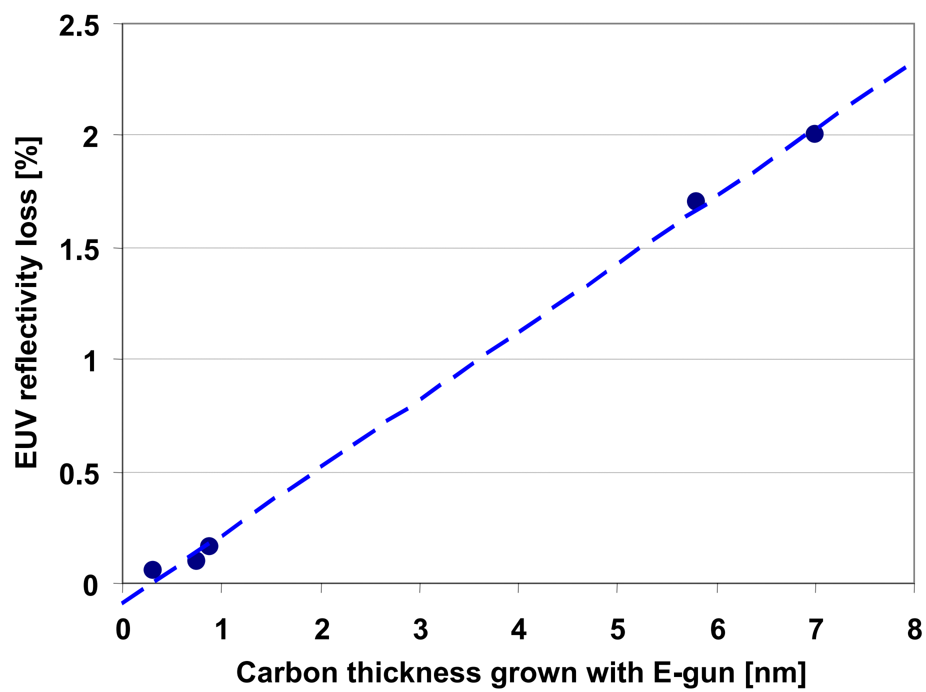
measurement after 10 hours

Species	**spec [mbar l/s]**	**measurement [mbar l/s]**
H_20	$<5x10^{-6}$	< lower detection limit (LDL)
$C_xH_{y:}$ 45-100 AMU	$<2x10^{-8}$	< LDL $<5\ 10^{-9}$
$C_xH_{y:}$ 100-200 AMU	$< 2x10^{-9}$	< LDL $< 5\ 10^{-10}$

E-beam test enables fast and low cost resist screening







EUV resist progress is steady and supplier roadmaps match our targets

Measured historic resist performance translated to expected imaging using proven relation between resolution , LER and dose, for following cases:

- ○ NXE:3100: NA=0.25, conv. Illumination, 10mJ/cm^2 7% LER
- △ NXE:3300: NA=0.32, conv. Illumination, 15mJ/cm^2 7% LER
- ◇ NXE:3300: NA=0.32, off axis Illumination, 15mJ/cm^2 7% LER

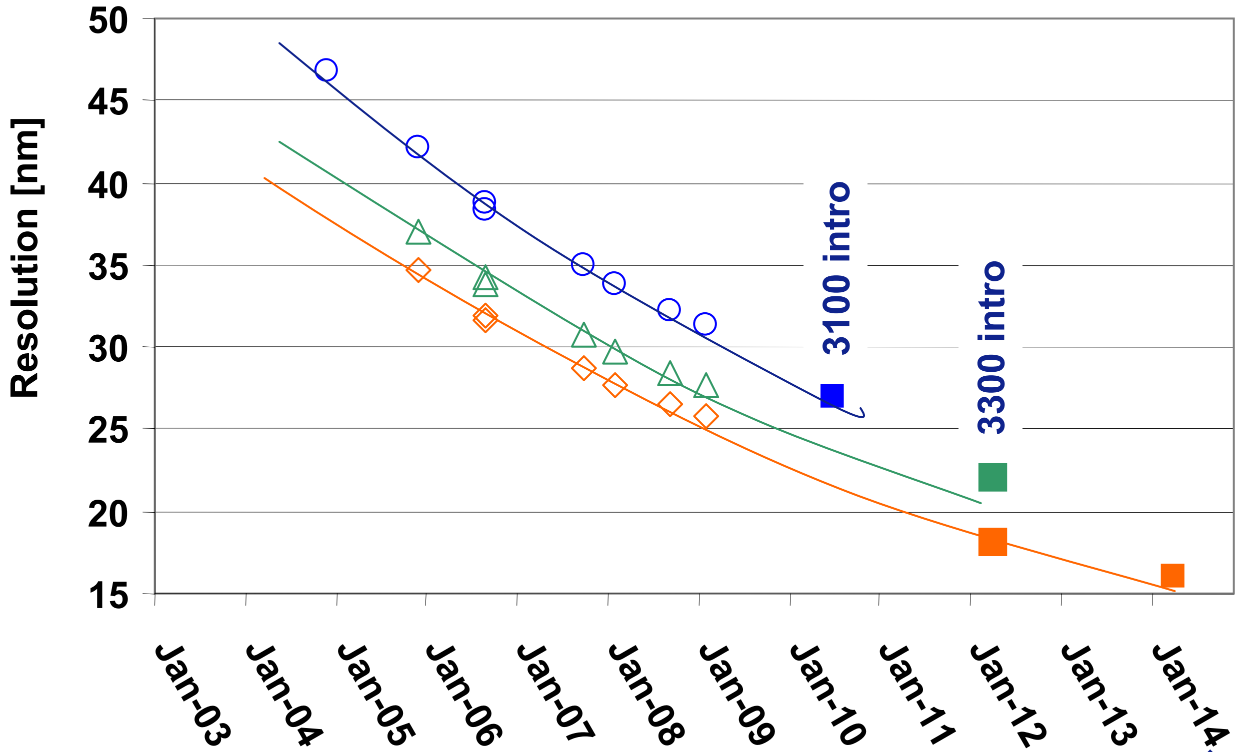
$$R^3 \cdot L^2 \cdot D = Const$$

$R = resolution$

$L = LWR$

$D = Dose$

$$R_1 = \sqrt[5]{\left(100 \cdot R_0^3 \cdot L_0^2\right)}$$



Koen van Ingen Schenau, ASML, private communication

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Agenda

- History
- Key system technology
- ASML system roadmap
- Infrastructure
- Summary & conclusions

Summary & conclusions

- EUV lithography is considered as the only viable cost effective Next Generation Lithography for 22nm and beyond.
- Extension of existing wavelength become increasingly difficult hence EUV transition will happen within the next few years.
- Yet much remains to be done: in particular the mask infrastructure needs a boost.
- Given the very large worldwide momentum (which will be made clear throughout this symposium) ASML is confident transition to EUV will be successful.

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Acknowledgements

The work presented has been the result of a hard work by teams at many technology partners worldwide over many years with a common goal to make EUV lithography happen.

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